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How density, diversity, land use and neighborhood type influences bus mobility in the Swedish city of Karlstad: Mixing spatial analytic and typo-morphological approaches to assess the indirect effect of urban form on travel

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Abstract: In the research on the effect of urban form on travel, a set of D-variables (density, diversity, design, destination accessibility, etc.) describes land use. Typo-morphology studies the historical emergence and evolution of urban patterns and their elements. In the typo-morphological approach, land use is an underlying element of neighborhood type. Neighborhood type defines urban areas that are relatively similar according to a range of attributes, such as building types, lot sizes, street layouts and land uses. This paper juxtaposes these two approaches to investigate the effect of density and diversity, land use and neighborhood type on bus mobility in the Swedish city of Karlstad. The results show that the number of residents and jobs in standard 400-meter walksheds around bus stops explains a third of the variation in bus ridership, which corresponds to previous studies in Sweden. The scatter plots with neighborhood types indicate that bus patronage variables and the D-variables cluster in intervals. This information about ranges and maximums in bus patronage in different neighborhood types is particularly important for urban designers and planners who work with typologies, form-based codes (FBCs) or transit-oriented development (TOD).

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1 Introduction

The effect of land use on travel is the most heavily researched topic in urban planning (Ewing & Cervero, 2010). Within this research tradition that abridges urban planning and transportation, the land use is often conceived as a set of D-variables: density, diversity and design (Cervero & Kockelman, 1997); Distance to transit and destination accessibility (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009); Demand management and Demographics (Ewing & Cervero, 2010). Much of this transportation-related research on urban form also fits in a wider morphological tradition of science of cities, urban modelling and systems (Batty, 1976, 2005, 2017; Wegener, 1994; spatial analytic approach in Kropf, 2009) where the city is defined as n-dimensional space and aggregation of N individuals in interaction (Chadwick, 1971).

Researchers within the systems approach/spatial analytic tradition build mathematical models of urban structure and dynamics in order to inform planning (Batty, 2017, p. 242). The D-variables usually include multiple parameters (often clustered as a product of factor analysis, e.g., Cervero, 1989). The practical challenge with implementation of the D-variables in urban design and planning processes is complexity, which comes with increasing number of parameters and interrelationships to be controlled. Researchers tend to include more and more variables (Park, Choi, & Lee, 2015) which produces sometimes information overload. This paper juxtaposes methods from the spatial analytic and the typo-morphological tradition in order to simplify the increasing complexity of spatial analysis, find synergies and link these approaches. Typo-morphology focuses on the physical form of cities and their evolution from formation to the subsequent transformations, by identifying and dissecting its various elements (Moudon, 1997, p. 3), or recognizing and abstracting urban forms and patterns (Marshall & Çalişkan, 2011, p. 421). The research from typo-morphological tradition (Conzen, 1960; Alexander, 1979; Whitehand, 2001; Cataldi, Maffei, & Vaccaro, 2002; Cataldi, 2003; historico-geographical and typo-processual approaches in Kropf, 2009) produces typologies of urban patterns and processes, design and plan elements and rules of combining elements into patterns. Neighborhood type within the typo-morphological approach characterizes areas of cities that are relatively homogeneous according to a range of attributes like age and style of development or street network type (Stead & Marshall, 2001, p. 128). Many urban morphologists, especially in Sweden, argue that neighborhood type explains not only density variables as residential density, Floor Space Indices (FSI) as built space density, etc. (Rådberg, 1988; Rådberg & Friberg, 1996), but also social structure and development tendencies (Engström et al., 1988). The planning authorities in Stockholm (SSBK, 1997, 2000) and Malmö (MSBK, 2000) have continuously used neighborhood typologies in urban planning processes, especially as background for urban design and form-based codes.

This paper is a summary of a larger report about Bus Rapid Transit (BRT) and Transit-Oriented Developments (TOD) in the city of Karlstad that have investigated the questions: What is the effect of urban density on bus patronage (in terms of trip generation)? Which urban density can support a 10-minute bus service? Karlstad is a small Swedish city with around 60000 inhabitants. It is a vibrant business hub of the Varmland region with over 40000 work places. The city of Karlstad struggles with unsustainable mobility patterns. Walking and cycling are under 10%. The car dominates journeys even under 1 km, reaching almost 90% modal share for journeys between 10 and 50 km. The share of public transportation is under 10% (Trivector, 2005, pp. 42-7). To mitigate the fossil fuel and automobile dependence, the municipality of Karlstad and Karlstadsbuss, the public transit authority, have undertaken an initiative to introduce a new BRT line and trigger TOD around the bus stations. In the effort to estimate the future bus patronage, the report set a wider theoretical framework to look at trip generation based on land uses and neighborhood types as nominal composite variables in addition to the D-variables. Since Swedish planning authorities commonly use neighborhood typologies in Swedish in urban design and development processes, the aim is to inform urban designers and planners about bus mobility patterns in respect to density, diversity and specific land uses and neighborhood types.

2 Theoretical framework and research hypothesis

Cities experience cycles of intensive development, building booms followed by slumps (Whitehand, 1987). Technological revolutions, new planning paradigms, social and economic transformations, etc. trigger building booms. The neighborhoods that emerge during major building booms display similar architectural styles and urban patterns, building and transportation technologies dominant for that specific historical era. The urban patterns include combinations of design and plan elements (building and street types, street layouts, lot sizes, land uses, etc.). When a particular urban pattern emerges, it acquires a special meaning and status in society. It becomes a neighborhood type. Society creates neighborhood types in order to simplify communication and promote values (Franck, 1994, p. 345). When individuals or households look for a new residence, they search for a particular type of home and neighborhood. The taste for housing triggers social mobility and grouping of 'housing classes' (Rex, 1971). Bourdieusien conceptualization of social class by taste helps to understand housing classes. Social classes are groups of agents who occupy similar positions in social space and who, being placed in similar conditions and subjected to similar conditionings, have every likelihood of having similar dispositions and interests and therefore of producing similar practices and adopting similar stance (Bourdieu, 1985, p. 725). Individuals and households with similar housing preferences create a housing class and settle in their favorite neighborhood type. Housing classes in typical neighborhoods become social stereotypes with similar lifestyle and behavior, social and economic characteristics (Figure 1A).

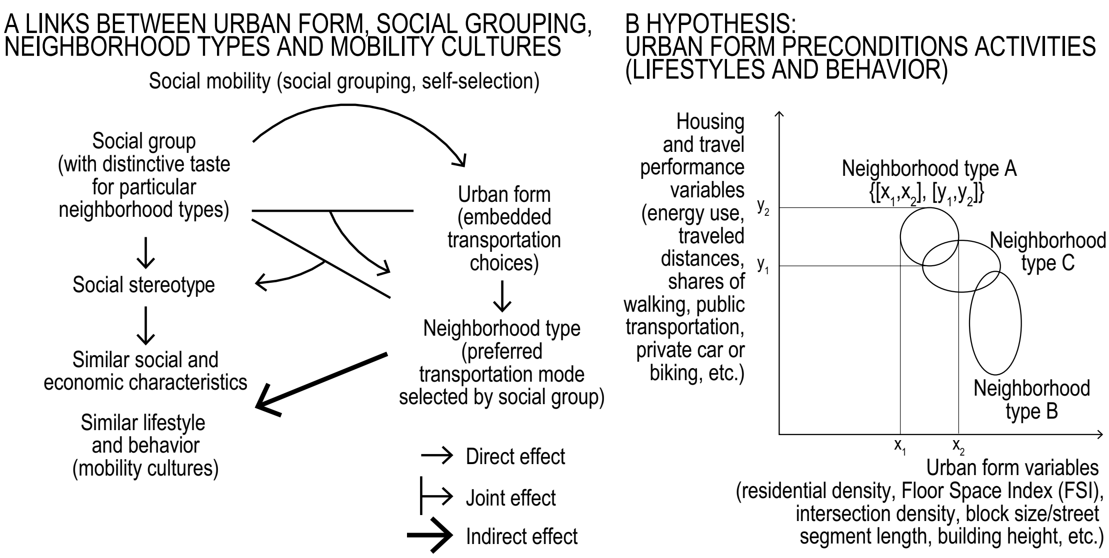

Figure 1: The link between urban form, social groups, neighborhood types and mobility cultures and hypothesis on the effect of urban form on travel

Neighborhood type incorporates a range of physical (urban form) variables inherited from morphological consistencies in historical evolution of cities and indirectly even socioeconomic and demographic variables as a consequence of social grouping and housing class formation (Figure 1B). Typical urban forms (characterized by urban design of specific historical period) do not determine how people travel, but they delimit the performance of different transportation systems. The effect on travel is indirect. Physical elements of the neighborhood design (parking standards, street layouts, etc.) precondition lifestyle and behavior, e.g., mobility. The urban pattern of the neighborhood (especially street design and layout) hinders or facilitate movement by prioritizing specific transportation modes. It is very difficult and sometimes impossible to drive a car or operate buses in the narrow streets of the pre-industrial neighborhoods (e.g., in the European old urban cores). A house with a garage and big box shopping malls with extensive parking lots in the suburbs precondition private mobility, long journeys and commutes. It is usually difficult to walk and bike there. The suburban house will probably attract a family with a car that will most probably drive around. Low suburban density is not a factor per se. A similar behavior occurs in a multifamily apartment block with a garage in the cellar, elevator to the apartment and quick exit to the expressway. The density does not matter as the historical integration with specific transportation modes. The research hypothesis in this paper is that neighborhood type, as nominal variable, would influence aggregated travel variables according to the formula [1]:

$$y = \boldsymbol{\beta}_1 \times x_1 + \boldsymbol{\beta}_2 \times x_2 + \ldots + \boldsymbol{\beta}_n \times x_n + \varepsilon \qquad (1)$$

y	an aggregated travel variable (average travelled distance, modal share of walking, cycling, public transportation or private car, etc.)
$x_{1\text{-}n}$	nominal variables (neighborhood types $x_{1\text{-}n}$)
$\boldsymbol{\beta}_{1\text{-}n}$	parameters for specific neighborhood types ($x_{1\text{-}n}$)
ε	error term

In a suburban neighborhood designed for car (designated as type x_3) the urban form variables (e.g., D-variables as density, diversity and design) would vary within a certain interval $[x_1, x_2]$ specific for that building boom period. The modal share for walking or traveled distances (designated as y) would range between y_1 and y_2 for that specific neighborhood type designated as x_3 (Figure 1B).

This theoretical framework derives furthermore from the tradition of aggregated studies in transportation engineering and research and urban design and planning. Aggregated refers to data or analysis at the zone, neighborhood or city level, and to travel patterns (modal split, numbers of trips for a zone, etc.), whereas disaggregated to data or analysis at the level of the individual (or household) and their discrete travel choices (Handy, 1996). There are two approaches in aggregate studies. In the first approach, it is common to compare representative neighborhoods: transit-oriented versus conventional suburban development (Cervero & Radisch, 1996; Stead & Marshall, 2001, p.128) or neighborhoods typical for different epochs (Southworth, 1997). In the second approach, researchers analyze aggregated variables of urban form and travel with statistical methods. It is common to look at trip generation rates by specific land uses (ITE, 2012) and to investigate the effect of density on travel variables (Pushkarev & Zupan, 1977; Newman & Kenworthy, 1989). The 'place-node model' (Bertolini, 1996, 1999, 2017, Chorus & Bertolini, 2011) is another similar method of aggregated analysis. The x-axis shows place variables (D-variables), whereas the y-axis node/transportation performance/travel demand variables (modal split, number of journeys generated, etc.). There are also other relevant studies that have looked at bus service characteristics (frequency, speed, stop spacing, separation, vehicle accessibility) in respect to bus performance and urban form variables (Currie & Delbosc, 2011).

3 Methods and data

The statistical data comes from the municipality of Karlstad and Statistiska centralbyrån (SCB, Statistics Sweden). It includes two statistical packages AMPAK and FASTPAK from SCB for year 2009 (at NYKO4 level). AMPAK (ArbetsMarknadsPAKet) shows employment, labor and income statistics, whereas FASTPAK (FASTtighetsPAKet) incudes statistics about real properties, floor space uses and FSIs. Karlstadsbuss have provided bus statistics (automatic passenger counts for boarding).

The Geographic Information System (GIS) data and maps are from Lantmäteriet's (National Land Survey of Sweden) Digital Library and municipality of Karlstad. The Swedish municipalities are responsible to divide their territory in six levels of NYKO areas for statistical purposes. NYKO or NYkelKOder translate as (key codes) zip codes. The number designates digits, e.g., NYKO3 has three digits (123) and includes NYKO4 zip codes with four digits (1230, 1231, 1232, etc.). The sizes of the NYKO statistical areas are different for different municipalities. NYKO4 in Karlstad usually vary between 200 m in length and width (in the central) and 1 km (in the peripheral areas). The NYKO4 area with null in the end (like 1200) designates the entire street area of the consecutive NYKO4 numbers (for example 1200 for 1201 and 1202). To do a proper calculation for density, the neighborhood borders include part of street space (NYKO4 areas with null in the end).

Figure 2 illustrates the orientation of the neighborhoods often as several merged NYKO4 statistical areas to the bus stops and trunk lines. Swedish transit professionals and urban designers consider walking distance 300-400 m to a bus stop as comfortable. The statistical areas do not fit ideally to the catchment areas of the bus stops, but the tendency is to make the best possible match. If two or more NYKO4 statistical areas are merged, the statistics are summed. The aggregation applies if the neighborhood has two or more bus stops. The number of passengers boarding at one or two bus stops are also summed.

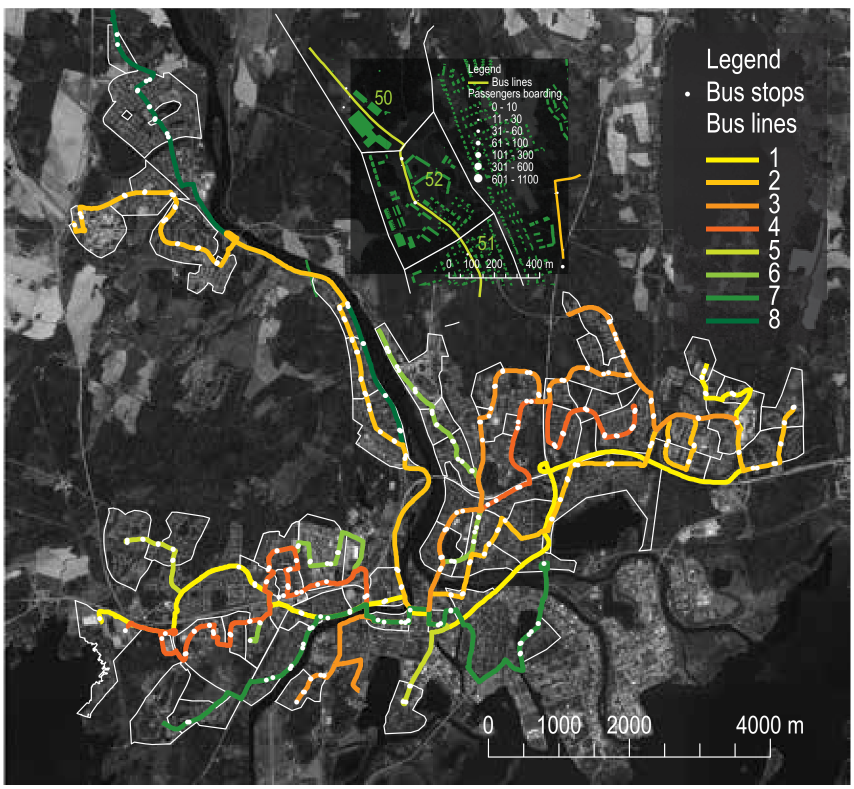

Figure 2: Method of delineating neighborhoods in respect to the statistical NYKO4 areas and orientation to the bus stops and primary lines

The bus statistics include only data for boarding on the primary lines. The secondary and tertiary network generate additional patronage. Karlstad has an urban bus system with radial hierarchical network. The primary network consists of eight trunk lines (with higher frequencies). The system map looks like a subway map with eight lines (Figure 2 shows bus lines 1-8). There are also secondary service lines during rush hour not included on Figure 2. When Färjestad BK, the local hockey team, plays, the bus network expands. A tertiary network of hockey buses emerges to bring Karlstadsborna, the inhabitants of Karlstad, to and from the Färjestad arena (ID50). Karlstadsbuss operates also boats that traverse the delta of Klarälv that cuts through the city. The eight trunk lines meet in a central station. This bus stop is not in the analysis. The passengers transfer between lines on this stop and the number of passengers boarding does not relate to the number of jobs and residences.

The typo-morphological survey of the city of Karlstad combines three Swedish typologies (Engström et al., 1988; Rådberg, 1988; Rådberg & Friberg, 1996; SSBK, 1997, 2000). Swedish neighborhood typologies focus predominantly on classifying residential neighborhoods. This typology includes additional neighborhood types with business and industry land use in addition to the original (Engström et al., 1988; Rådberg & Friberg, 1996; SSBK, 1997, 2000). The inspiration for these commercial types comes from American typologies of shopping malls (Southworth, 2005) or shopping districts (Scheer, 2015). Appendix 1 describes the method and typology in detail.

Karlstad have experienced a typical urbanization pattern of growth. Figure 3 shows the results, patterns of typical neighborhoods and their IDs. There are 88 typical neighborhoods (14 types), but only the first 55 fit in the primary network bus service areas (only 13 types, there are no kontorkomplex type of neighborhood near transit) of the bus stops. Most of the neighborhoods correspond to the Swedish typology presented in Appendix 1.

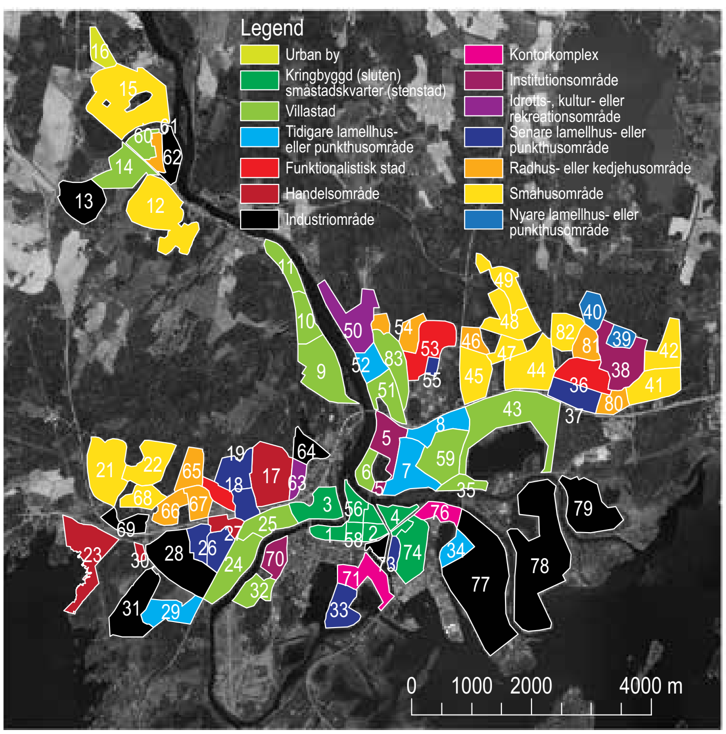

Figure 3: Typical neighborhood in the city of Karlstad

The statistical analyses include two methods. Regression analyses investigate the direct effect of density and diversity on transit ridership. The dependent variable is absolute number of passengers boarding the bus stops in the neighborhood or passengers boarding per resident and job. This unconventional variable is relevant in a context of trip generation rates. One of the aims of the report is to estimate ridership based on average trip generation rates per resident and job. The absolute numbers of residents, jobs and residential and commercial floor space (FSI represents a rate between total taxable floor space in the buildings and neighborhood area) is available directly from the statistical packages (AMPAK and FAST-PAK). The residence-job (residential and commercial floor space) entropy defines diversity. Entropy is one of three measurements for diversity (Cervero & Kockelman, 1997). Batty (1974) have proposed a spatial entropy formula [2] and Cervero (1989) used it in a context of jobs and residences balance.

$$E_i = -\frac{\sum_{i=1}^{n}((P_i \times \ln(P_i))}{\ln(N)} \tag{2}$$

E_i Entropy
P_i Proportion of categories 1-n (e.g., of residents P_1 and jobs P_2)
N Number of categories (2: residents and jobs)

The second statistical method compares the means for diversity, different land uses and neighborhood types as nominal variables. The classification of neighborhood types and land uses is described later in Appendix 1 and 2 respectably. The neighborhoods with between 20% and 80% mix of residences and jobs, or residential and commercial floor spaces are designated as 'Mixed' in the diversity categories. 'Low density' assumes less than 50 residents or jobs per hectare and 'Mixed' is entropy of 0.5 or higher in the density and diversity categories. Passengers boarding per resident and job is used as dependent variable in the comparison of the means.

4 Results and discussions

4.1 The effect of density and diversity on bus patronage

Density refers to absolute number of residents, jobs, residents and jobs and built density (FSIs). Density usually implies household, residential or employment density, but also parcel density, business density, etc. (Ewing & Cervero, 2010, p. 287). Residential or employment density of a statistical area (NYKO4) comes as product of dividing with the size of the area measured in hectares or acres. This is best applicable when the statistical areas do not include non-built areas such as forests. Many NYKO4 areas include a chunk of the surrounding forest in the entire statistical area and all the buildings are close to the road where the bus stop is. If the number of residents or jobs divides the entire area of the statistical area, it will sometimes (usually in the suburbs) show much lower number for residential or employment density. Therefore, absolute number of residents and jobs replaces here residential or employment density. The catchment areas that surround a bus stop are roughly same (within a standard walking radius of 300-400 m). There are some neighborhoods with buildings out of this standard walkshed, but there are no closer bus stops around. These buildings and their residents belong in wider catchment areas and gravitate to the bus stop. This makes the analysis approximate. However, research shows that a quarter of the bus passengers walk beyond 400 m (Daniels & Mulley, 2013; El-Geneidy, Grimsrud, Wasfi, Tétreault, & Surprenant-Legault, 2013) and that makes it difficult to define exact boundaries of catchment areas even with standard service areas.

In a context of neighborhoods as catchment areas with roughly same sizes, this paper analyzes the sum of residents and jobs as an activity index in the neighborhood. Homes and working places create demand for travel. In this analysis, one resident and one job weigh equally. In practice, travel demand for jobs varies much more than for residents. Jobs, especially in the commercial sector, generate additional visitors. Jobs in suburban shopping mall like IKEA generate much more travel per job than luxurious shops (jewelers, art galleries, etc.) in the downtowns. The justification for using a sum of residents and jobs is in its application for urban design or planning practice. Urban designers and planners usually work with number of dwelling, number of residents to house or number of jobs to create. The statistical packages include over 200 variables including statistics by age groups, types of jobs, etc. A theory-driven analysis would run multivariate stepwise regression to seek variables with highest statistical significance. A practice-driven analysis that aims to inform urban designers or planners would target variables that are in common use such as number of residents or jobs. In practice, it is difficult to control age groups, types or jobs, etc. that are common in multivariate analyses.

Regression analysis estimates the parameters and assesses statistical significance of density variables. Table 1 shows the results of the regression, whereas Figure 4 presents the scatter plots for Model 1-3 and 5. The explanation coefficient (R squared) is much better and statistically more significant for residents (R_2=0.166, Sig=0.002) than for jobs (R_2=0.117, Sig=0.011) that corresponds to the empirical and practical evidence. It is more difficult to forecast travel demand for jobs than for residents. By combining residents and jobs in one aggregated variable in Model 3 or by looking them as two separate variables in the Model 4 both the explanation coefficient and their significance increases (R2=0.293 and R2=0.296 respectably). Absolute number of residents and jobs roughly explains 30% of the bus passenger boarding variation. These results also correspond to Swedish experiences where residential density explains roughly a third of the variation (Holmberg, 2013). In the classical aggregated studies, density explains 50-60% of the variation (Pushkarev & Zupan, 1977). The relationship between FSI and bus passengers generated per resident or job (Model 5) shows insignificant statistical results. The scattered plots (Figure 4) illustrate the relationships.

Table 1: Linear regression analysis of passengers boarding (Model 1-4), passengers boarding per hectare and passengers boarding per resident and job (Model 5) as dependent variables

Model 1	Coefficient	Std. Error	t	Sig.
(Constant) [a]	77.252	46.425	1.664	0.102
Residents [a]	0.122	0.038	3.251	0.002
F (Sig.) = 10.567 (0.002)				
R Square = 0.166 (Adjusted R Square 0.151)				
Model 2	Coefficient	Std. Error	t	Sig.
(Constant) [a]	147.353	35.241	4.181	.000
Jobs [a]	0.149	0.057	2.644	.011
F (Sig.) = 6.993 (0.011)				
R Square = 0.117 (Adjusted R Square 0.100)				
Model 3	Coefficient	Std. Error	t	Sig.
(Constant) [a]	22.079	45.677	0.483	0.631
Residents and jobs [a]	0.137	0.029	4.683	0.000
F (Sig.) = 21.926 (0.000)				
R Square = 0.293 (Adjusted R Square 0.279)				
Model 4	Coefficient	Std. Error	t	Sig.
(Constant) [a]	24.701	46.281	0.534	0.596
Residents [a]	0.127	0.035	3.643	0.001
Jobs [a]	0.158	0.051	3.099	0.003
F (Sig.) = 10.942 (0.000)				
R Square = 0.296 (Adjusted R Square 0.269)				
Model 5	Coefficient	Std. Error	t	Sig.
(Constant) [b]	0.097	0.047	2.049	0.045
Floor Space Index [b]	-0.239	0.203	-1.181	0.243
F (Sig.) = 1.395 (0.243)				
R Square = 0.026 (Adjusted R Square 0.007)				
Number of neighborhoods = 55				
[a] Dependent Variable: Passengers boarding				
[b] Dependent Variable: Passengers boarding per resident and job				

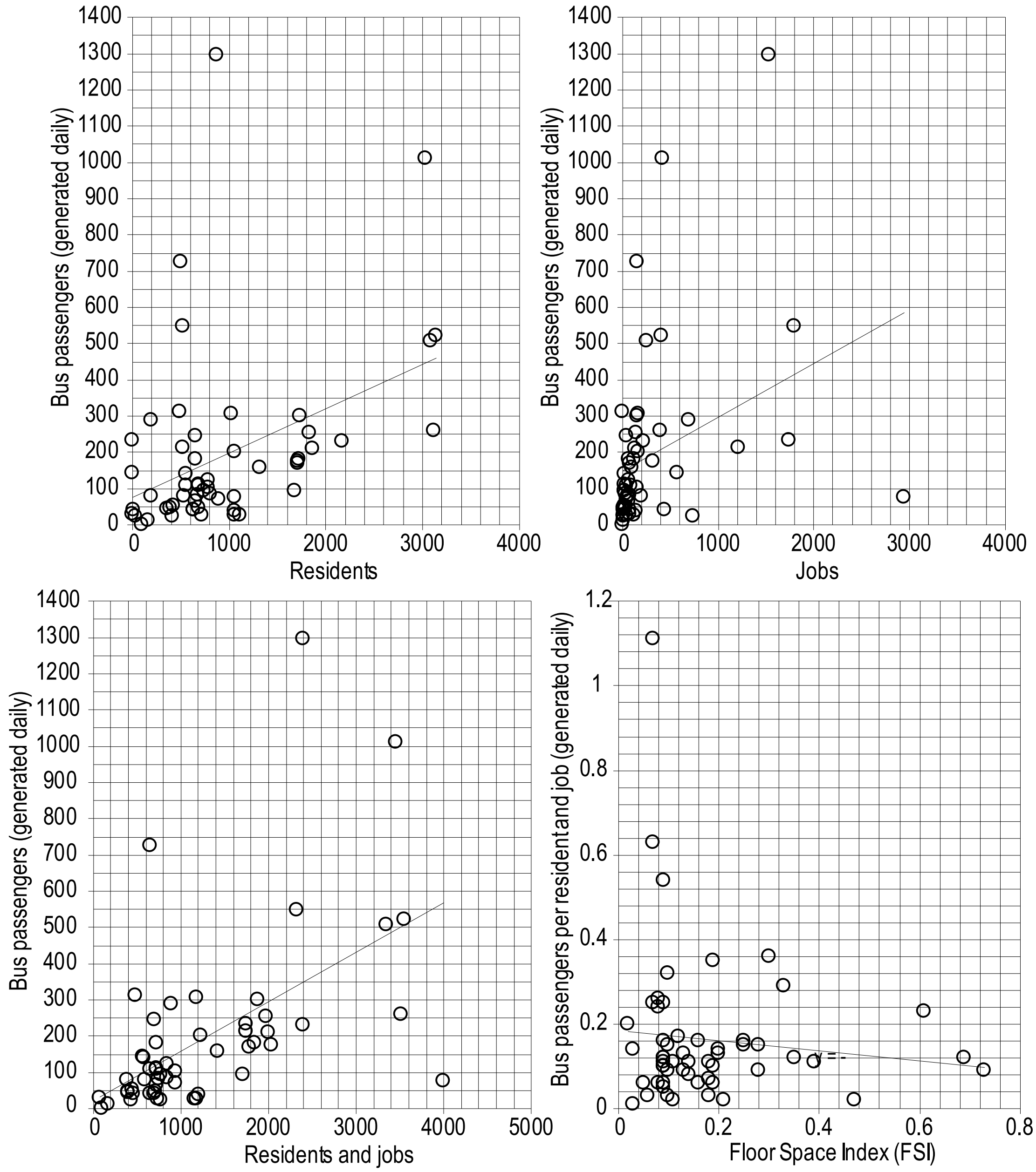

Figure 4: Urban density and bus patronage in scatter plots

There are three index measures for diversity as D-variable (Cervero & Kockelman, 1997). This paper investigates diversity as entropy of residents and jobs or residential and commercial floor spaces. Regression analysis estimates the parameters and assesses statistical significance. Table 2 presents the results of the regression analyses, whereas Figure 5 shows the scatter plots of the diversity variable.

Table 2: Linear regression analysis of passengers boarding per resident and job (Model 1-2) as dependent variables

Model 1	Coefficient	Std. Error	t	Sig.
(Constant)	0.050	0.052	0.964	0.339
Entropy of residents and jobs	0.255	0.108	2.354	0.023
F (Sig.) = 5.542 (0.023)				
R Square = 0.100 (Adjusted R Square 0.082)				
Model 2	Coefficient	Std. Error	T	Sig.
(Constant)	0.154	0.049	3.165	0.003
Entropy residential and commercial floor spaces	0.007	0.099	0.073	0.942
F (Sig.) = 0.005 (0.942)				
R Square = 0.000 (Adjusted R Square -0.026)				
Number of neighborhoods = 55				
Dependent Variable: Passengers boarding per resident and job				

The scattered plots (Figure 5) show a dispersal with many residuals. The trendline fits better entropy of residents and jobs.

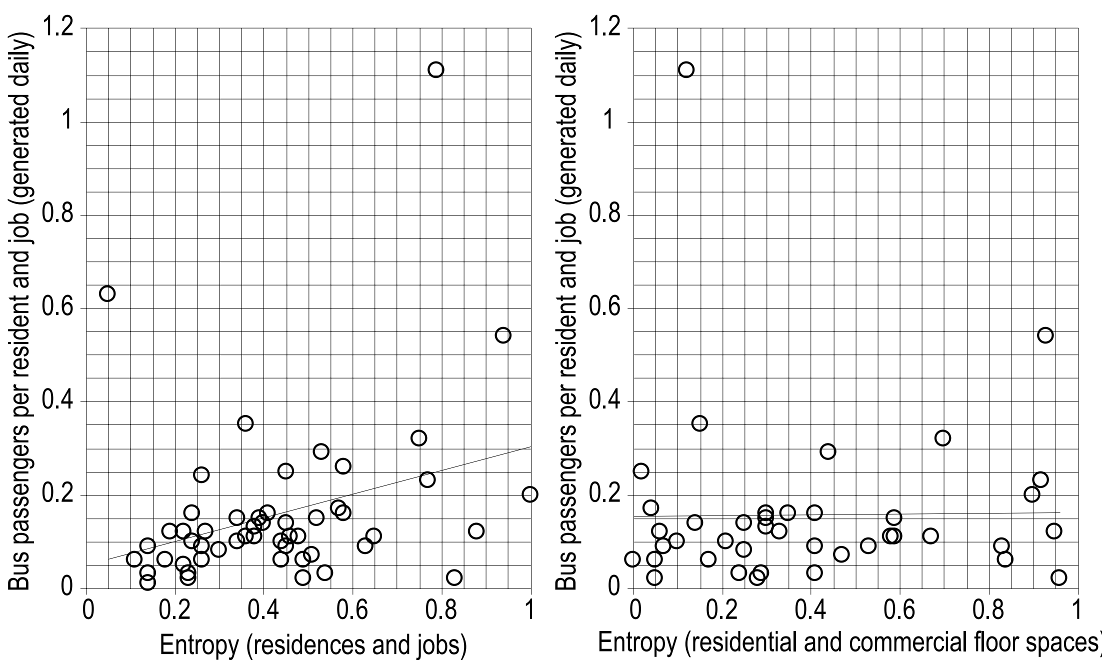

Figure 5: The effect of diversity as scatter plots

The explanation coefficient for entropy of residents and jobs explains roughly 10% of the variation (R^2=0.100, Sig=0.023), whereas the entropy of residential and commercial floor spaces is insignificant as independent variable.

4.2 How land use and neighborhood type influence bus patronage?

Appendix 2 and 1 includes classification categories for land uses and neighborhood types. The method comparison of means in SPSS is used to analyze the nominal data and statistics. The ANOVA tables are not presented in the results, because the large number of categories for land uses and neighborhood types produce high etas (η^2). With high explanation coefficients for measure of association, this might be misleading. The real reason for such results would be small samples for many land uses and neighborhood types.

The scatter plots and bar charts with error bars on Figure 7 illustrate how land use influences bus patronage. Each values on the scatter plots receives a land-use category. It is possible to see intervals for both D-variables and generation of bus passengers. The scatter plots and bar chars (Figure 7) show that community services generate much more bus passengers than the other land uses. Karlstad's University and the biggest high school in Karlstad are located in these two neighborhoods. This analysis does not include generation of journeys per student place at the university or high school. Students tend to be the most loyal transit users in Sweden. That might cause the high rate of passengers boarding per resident and educational job.

The bar charts with error bars (Figure 6) and descriptive statistics for land uses (Table 3) show high standard deviations and ranges (large intervals), especially for the residential areas for passengers boarding per resident and job. Most of the residential areas cover the range between roughly 0.01 and 0.20 passengers generated per resident and job. The retail and professional services are second behind community services in generation of passengers per resident and job [0.13, 0.36].

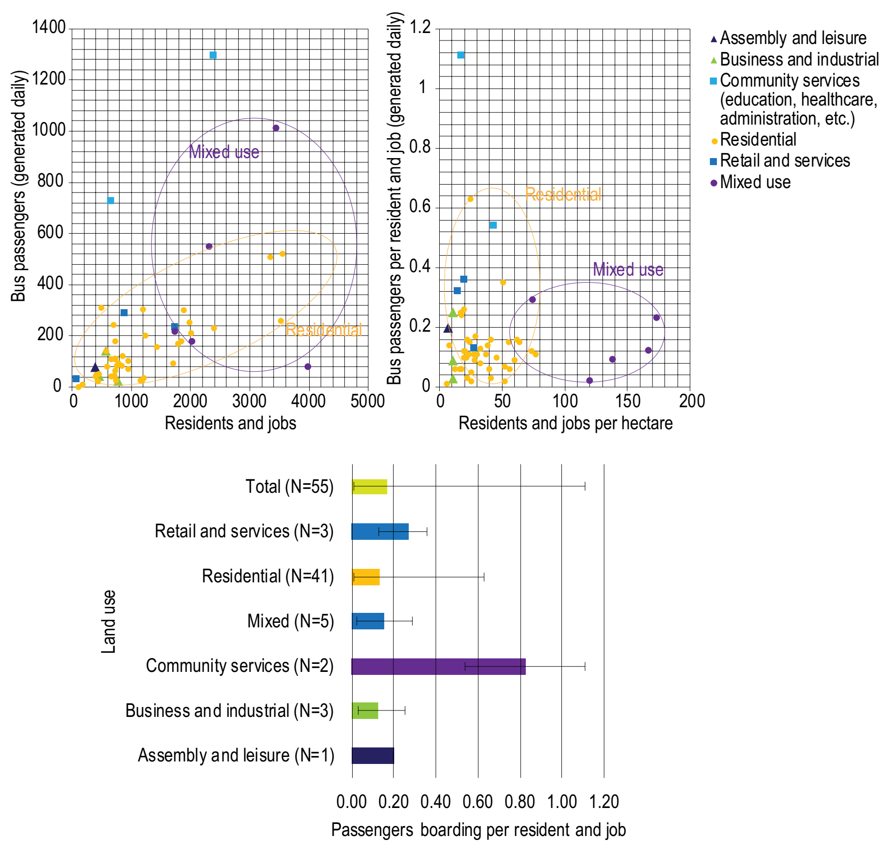

Figure 6: How land use influences bus patronage

Table 3: Descriptive statistics for land uses – bus passengers boarding per resident and job

Land use	Mean	Std. Deviation	Minimum	Maximum	N
Assembly and leisure	0.2000		0.20	0.20	1
Business and industrial	0.1233	0.11372	0.03	0.25	3
Community services	0.8250	0.40305	0.54	1.11	2
Mixed	0.1500	0.10886	0.02	0.29	5
Residential	0.1278	0.10620	0.01	0.63	41
Retail and services	0.2700	0.12288	0.13	0.36	3
Total	0.1640	0.17667	0.01	1.11	55

Neighborhood type as category incorporates a combxination of land use, building types, lot sizes and different types of street layouts. Appendix 1 explains the typo-morphological method and presents a Swedish neighborhood typology. This paper uses the original Swedish names for neighborhood types. The translations are in the appendix (Figure 11). Neighborhood type is kind of a brand in Swedish society and the direct translation, e.g., 'villastad' or 'funktionalistisk stad' makes no sense to English or Swedish readers as 'city of villas' or 'functionalistic city.'

Figure 7 illustrates scatter plots of different urban form variables (as independent variables) with bus patronage (as dependent). Each value point receives a neighborhood type characterization. Intersection density is calculated in ArcGIS with the Spatial Join tool after VISUM automatically assigned the number of links that connect each node (1 link = 1 cul-de-sac; 2 links = L intersection, 3 links = T-intersection etc.). Distance to the center is measured with Network Analyst tool in ArcGIS from the centroid of each neighborhood to Stora Torget, the central square in Karlstad. Table 4 shows the descriptive statistics for passengers boarding per resident and job for neighborhood type. As hypothesized in Figure 1, the categorization of the scatter plots reveals intervals, but they are more visible in respect to different D-variables. These intervals are smaller for residents and jobs per hectare, distance to the center and income and they are bigger for intersection density and entropy. These results at least confirm the prepositions from Swedish urban morphology (Engström et al., 1988; Rådberg, 1988; Rådberg & Friberg, 1996) that the neighborhood types describe number of D-variables, location and income, an economic factor.

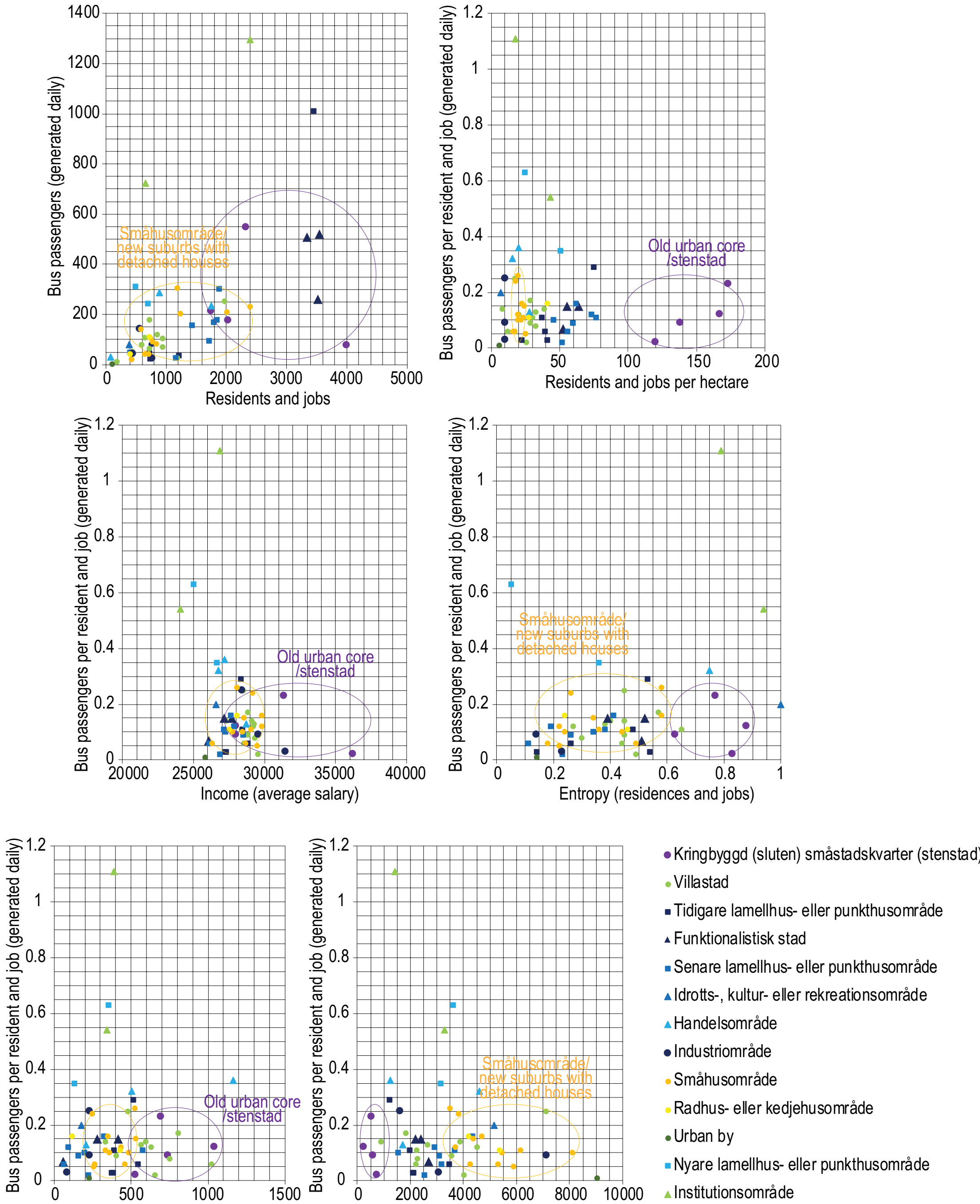

Figure 7: The effect of neighborhood type as scatter plots

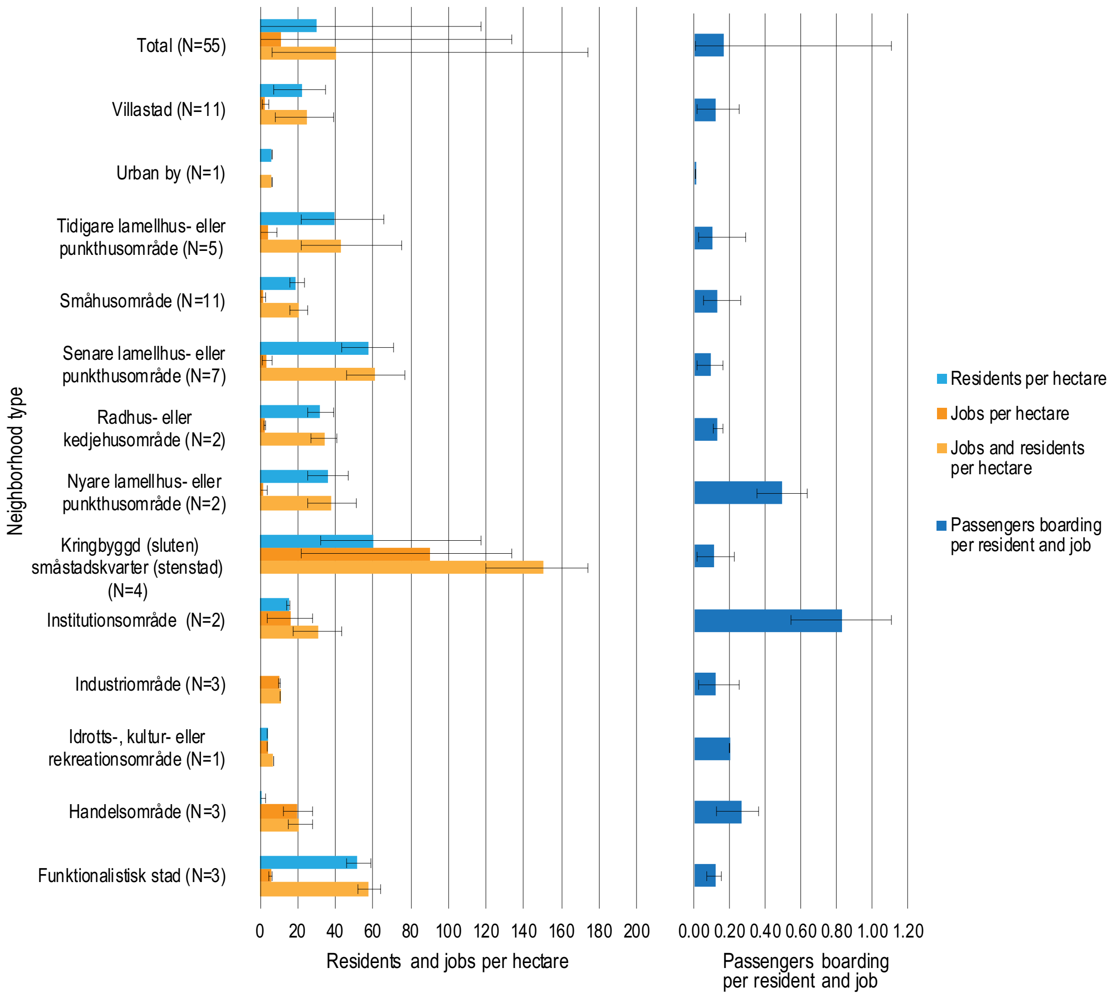

Figure 8: The effect of neighborhood type as bar charts with error bars

The bar charts (Figure 8) and descriptive statistics for neighborhood types (Table 4) however show that despite the classification the different types of residential areas cover the range between roughly 0.01-0.11 and 0.20 passengers generated per resident and job. The detailed neighborhood typology does not contribute to intervals that are more precise for bus trip generation.

Table 4: Descriptive statistics for neighborhood types – bus passengers boarding per resident and job

Neighborhood type	Mean	Std. Deviation	Minimum	Maximum	N
Funktionalistisk stad	0.1233	0.04619	0.07	0.15	3
Handelsområde	0.2700	0.12288	0.13	0.36	3
Idrotts-, kultur- eller rekreation-område	0.2000		0.20	0.20	1
Industriområde	0.1233	0.11372	0.03	0.25	3
Institutionsområde	0.8250	0.40305	0.54	1.11	2
Kringbyggd (sluten) småstadskvarter (stenstad)	0.1150	0.08737	0.02	0.23	4
Nyare lamellhus- eller punkthusområde	0.4900	0.19799	0.35	0.63	2
Radhus- eller kedjehusområde	0.1350	0.03536	0.11	0.16	2
Senare lamellhus- eller punkthusområde	0.0943	0.04467	0.02	0.16	7
Småhusområde	0.1282	0.06983	0.05	0.26	11
Tidigare lamellhus- eller punkthusområde	0.1040	0.10900	0.03	0.29	5
Urban by	0.0100		0.01	0.01	1
Villastad	0.1191	0.06041	0.02	0.25	11
Total	0.1640	0.17667	0.01	1.11	55

In the end, the statistical investigation (for example, regression analysis) in this paper is used to assess to which extend different D-variables do affect travel on aggregated level, rather than to forecast. It is possible to use general linear models as formula [1] to calculate its parameters (and propose models for trip generation based on neighborhood types), but there is a need of larger sample of neighborhoods for statistical significance.

5 Conclusion

This study shows an expansion from density and D-variables, via land use classification to a neighborhood typology. The absolute number of residents and jobs in a standard 400 m walkshed around the bus stops replaces residential and employment density in this paper. The statistical explanation of absolute number of residents and jobs in a neighborhood on the number of passengers boarding at the bus stops is roughly 30%. The hypothesis cannot be neither fully accepted nor completely rejected. These results also correspond to what is known and empirically proven in other studies on density in Sweden. Residential density roughly explains third of the variation in transit ridership (Holmberg, 2013). The measures for diversity, quantitative entropy and qualitative categories, show no significant effect. In a context of land use and neighborhood type classes, the descriptive statistics and the scatter plots (Figure 6 and 7) reveal intervals as it is hypothesized (Figure 1), but these intervals are more obvious for different D-variables as argued by Swedish urban morphologists (Engström et al., 1988; Rådberg, 1988; Rådberg & Friberg, 1996). Neighborhood type is a better predictor of land use (D-variables) than travel variables. The detailed neighborhood typology does not contribute to intervals that are more precise, but it shows ranges and maximums of trip generation rates for bus. Residential as land use has roughly the same interval as all the residential neighborhood types, but it makes distinctive intervals for the D variables (on the x-axis).

This paper is a summary of a larger report that aims to inform urban design and planning practitioners about the effect of urban form variables on bus patronage. The statistical database includes over 200 variables on age groups, employment, type of jobs, etc. With access to numerous variable and big data, researchers often run very complex multivariate models to assess the interaction between transportation and land use. This is a valuable research for theory building and conceptualizing, but practitioners that work with established urban parameters such as number of dwellings, residents or jobs (as absolute numbers or per hectare), FSIs, building heights, building types, form based codes, parking standards, etc. can experience an information overload. It is also difficult to control very detailed parameters such age groups, types or jobs, etc. in practice. Typo-morphology offers classification methods to simplify and refine concepts of land use by looking at design elements as building types, lot sizes and street layouts. This can be useful especially in Swedish cities for urban designers that already use neighborhood types in practice (SSBK, 1997; 2000; MSBK, 2000). Showing trip generation rates, residential and employment densities organized by neighborhood type would provide additional and valuable information for urban designers and planners. There are also discussions about improvement of manuals on trip generation (Clifton, Currans, & Muhs, 2015). Neighborhood type is a similar concept as the land use categories in the Trip Generation Manual (ITE, 2012). Trip generation relates to neighborhood types too. Neighborhood types are fewer and more closely resemble societal conceptualizations of urban areas and urban design practices.

There is other potential in converging research and concepts from typo-morphological and spatial analytic traditions. Typo-morphology, through the work of computer scientists, have entered urban modelling and research on land use and transportation interaction indirectly. There are new procedural models for generation of cities (see CityEngine, http://www.esri.com/software/cityengine; based on Parish & Müller, 2001) and software for creation of urban design scenarios such as UrbanFootprint (www.urbanfootprint.com). Some large-scale urban models, e.g., UrbanSim (www.urbansim.com) have integrated procedural modeling tools (browse for UrbanCanvas, currently defunct; based on Vanegas, Garcia-Dorado, Aliaga, Benes, & Waddell, 2012). These procedural models incorporate typo-morphological concepts about structure of cites. Neighborhood type is a combination of certain type of street, type of lot, building type, building façade type, etc. A new type of procedural-based large-scale urban models can include typologies of neighborhoods and procedural typologies (rules to combine urban form elements) used by urban morphologists and designers (see Kropf, 2014). The purpose of this would be not be to generate cities (the objective of CityEngine, UrbanCanvas, UrbanFootprint, etc.) but to seek and identify neighborhood (or place) types, make sense of big data by analyzing urban form and travel variables (in simplified form) in respect to typologies and inform urban designers and planners.

A simplified analytical approach (to look at few variables such as numbers of residents and jobs) and typo-morphological method show similar results. More jobs or residents near transit or having mixed and dense neighborhood types such as old urban cores ('stenstad') results in more passengers boarding the buses. In a way, they complement themselves. Disadvantage of using typo-morphology is that it requires qualitative studies on neighborhood or place types. To make this kind of analysis there is a need to develop a model of historical evolution of the city and inventory of neighborhood types. Another disadvantage of using typo-morphological methods is generalization. It is possible to abstract a neighborhood type and to use this abstraction as background to estimate residential or employment density or even trip generation rates. However, these results should be used with caution because no two neighborhoods that are same. If a historical neighborhood (e.g., a railway suburb of the early 20th century) is replicated as new TOD today, the neighborhood type will be different in historical context that will affect age groups, social grouping, etc., despite similarities in urban design, residential and employment density.

In the end, the purpose of this study is to analyze travel through a morphological perspective of neighborhood types (qualitative approach) and assess their effect through analytic (quantitative) methods. Overall, the combination of the research from typo-morphological tradition and methods of comparison of means is a novel method that can give additional aggregated insights on the effect of urban form on travel variables. The results are not deterministic, but approximate. The neighborhood type create intervals of values, maximums and minimums. This information can be valuable for urban designers, planners and politicians who work with form-based codes and typologies. The method of comparing means is applicable in other studies. For statistical significance, there is a need of larger sample of neighborhoods. A city results in a sample of hundred (small city as Karlstad) to few hundred or thousands typical neighborhoods in the larger cities. It is a direction for a future research. Another direction of implementation is to apply the knowledge about neighborhood types in informing about trip generation rates as part of urban design guidelines that seek to shape certain type of neighborhood (e.g., types of TODs) or using neighborhood types and their underlying elements in new kind of (morphologically informed) procedural urban models.

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Appendices

Appendices 1 and 2 are available online at https://www.jtlu.org/index.php/jtlu/article/view/1089.